Unravelling the Effects of Long Distance Water Transfer for Ecological Recharge

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Introduction

Long distance inter-basin water transfer infrastructure brings economic benefits to water-deficient regions through increased supply for domestic, industrial and agricultural water uses. However, it also generates adverse environmental and social impacts, such as water quality deterioration, habitat loss and forced immigration (Gupta and van der Zaag 2008; Wilson et al. 2017; Zhang et al. 2018). An environmental impact assessment for inter-basin water transfer projects is normally carried out at the planning stage, but this might not be comprehensive due to various reasons related to data availability, stakeholder engagement, institutional coordination, and regulatory frameworks. However, to be fully understood, environmental and ecological impacts should be fully analyzed during operation and, in particular, any unintended positive impacts should be explored. This paper discusses the unintended benefits of water transfer in ecological restoration using the South to North Water Transfer (SNWT) project, China as an example, and recommends future directions for sustainable planning and management of inter-basin water transfer infrastructures.

Inter-basin Water Transfer Projects

It is estimated there are about 350 water transfer projects in the world, including the Central Valley Project in the US and the SNWT project in China, providing a total annual water diversion capacity of 500 billion m^3. China alone has a total of 140 water transfer projects (including those currently under construction) and some key projects are shown in Figure 1. There are about 60 projects that have a pipeline or canal with either a length of over 50 km or an annual water transfer capacity of 100 million m^3, and these cover a total distance of 16,000 km and provide an annual diversion capacity of 100 billion m^3 (Yu et al. 2018).

The SNWT project (Barnett et al. 2015) is the largest inter-basin water transfer project in the world. The project currently includes the eastern and central routes, each of which covers a distance of more than 1,000 kilometers and crosses four major river basins: the

Yangtze River, Yellow River, Huai River, and Hai River. It can deliver 25 billion m^3 water per year from the Yangtze River to the North China Plain, which includes Beijing and Tianjin and is one of the most water-stressed regions in China. In the North China Plain, groundwater tables have been falling by 1 m per year, posing serious risks to agriculture and food security (Ministry of Environment 2013). A third route, the western route, is under planning and aims to divert 20 billion m^3 water from the Yalong River and Dadu River in the upper Yangtze River basin to the upper Yellow River to alleviate water shortages in Northwest China.

The central route of the SNWT runs from the Danjiangkou Reservoir on the Han River, a main tributary of the Yangtze River, through a gravity-based canal to Beijing and Tianjin, as shown in Figure 1. As part of this project, the height of the Danjiangkou dam was raised to allow the reservoir water level to be increased from 157m to 170m above sea level. This enables water to flow the whole distance from Danjiangkou Reservoir to Beijing by gravity, without the need for pumping. The project construction started on December 30th , 2003 and was completed in 2014, with a total investment of 182.3 billion RMB (Zhang et al. 2018). As of December 2018, 22.2 billion m^3 water had been transferred to Henan province, Beijing, Tianjin, and Hebei province, and more than 53.2 million people had benefitted (according to the website of the South-to-North Water Transfer Project, http://nsbd.mwr.gov.cn).

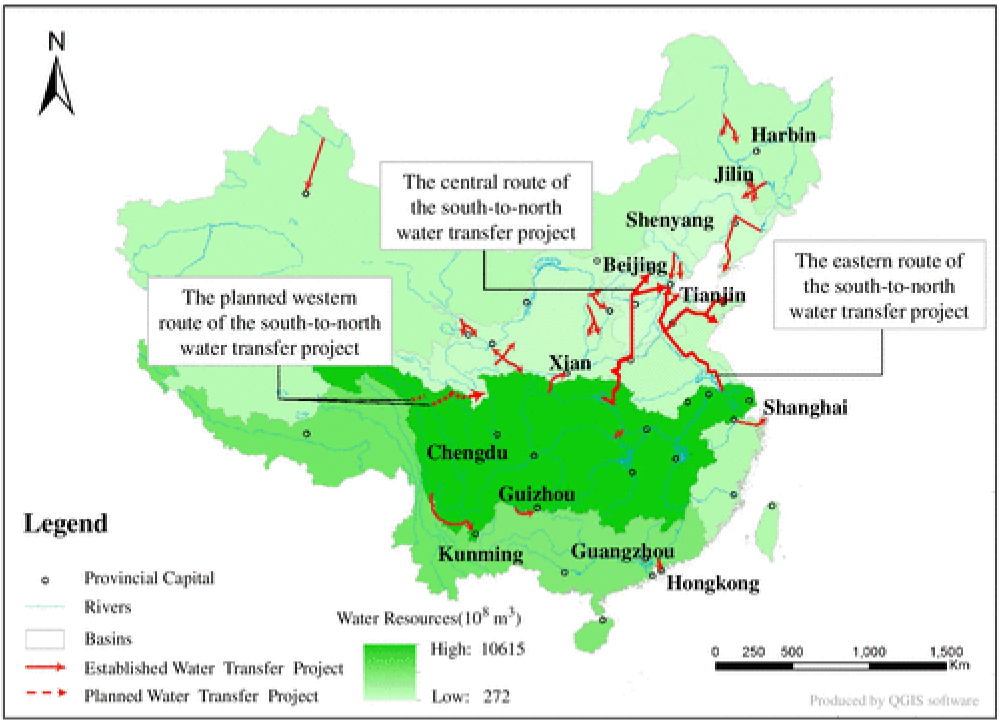

Figure 1. The major inter-basin water transfer projects in Mainland China.

Water Recharge for Ecosystem Restoration

Despite not being considered at the planning stage of the central route of the SNWT, water recharging for ecosystem restoration was tested in 2015 and 2017, with transfers of 2.7 million m^3 and 300 million m^3 water respectively to Henan. Further, a large-scale water recharge was conducted for the first time from April to June 2018 to alleviate the increasingly deteriorating ecological systems in the North China plain. This channeled 870 million m^3 water to 30 rivers in Henan, Hebei and Tianjin City and specifically recharged 112 million m^3 water to the Baiyangdian Lake alone (data from website http://nsbd.mwr.gov.cn), greatly increasing its water surface area (Figure 2). This increase was evident when comparing with the same period in 2014, which had similar total rainfall and evaporation. The groundwater level in the Beijing plain area was also 0.91m higher in 2018 than in the previous year, and the water quality at the four monitoring sections in the downtown of Tianjin was improved from Class III-IV to Class II-III. This was primarily attributed to the recharge.

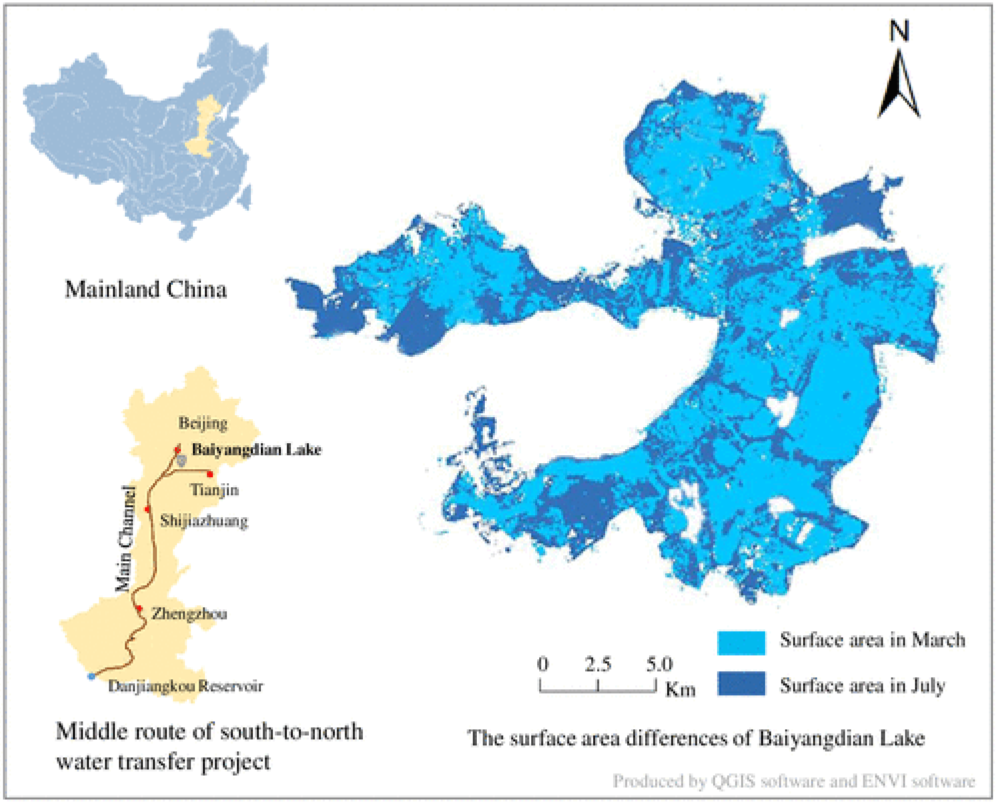

Figure 2. The water surface of Baiyangdian Lake before and after the 2018 recharge event, extracted from Landsat 8 Operational Land Imager (OLI) imagery (data from website https://earthexplorer.usgs.gov/).

During the 2019 flood season (August 6th-20th), the central route of the SNWT recharged 17 rivers, including the Baihe (Suohe), with a total volume of 120 million m^3. This ecological recharge event was carried out during the main flood season, when high rainfall posed a major test for flood risk management.

Recommendations

Environmental degradation is a key challenge faced by many countries due to population growth, urbanization, economic growth, and climate change. Restoration programs are a typical approach to improving environmental quality. However, they require large investments and can suffer from various problems. For example, the benefits of the national restoration program in China were significantly offset by droughts in several ecological restoration zones such as the Beijing-Tianjin Region (Wu et al. 2014). Nevertheless, water recharge through water transfer projects such as the middle route of the SNWT project provides a new method of ecological restoration to recharge lakes, rivers, wetlands and groundwater and can potentially generate high ecological benefits.

Ecological recharges such as those provided by the middle route illustrate that the SNWT inter-basin water transfer project can bring large unintended ecological benefits to the water-receiving regions during high flows (flood seasons) in the water source region. Undoubtedly, such water transfer infrastructures lock in large investments and a significant amount of carbon emissions during the whole life cycle, thus their value should be fully explored once constructed. The following points regarding recharges should be carefully considered to promote ecological restoration and environmental protection, safeguard water security, and achieve sustainable water resources management.

Considering ecological recharge at the project planning stage

Ecological recharge should be incorporated in the planning stage for large inter-basin water transfer infrastructures. Under current practice, low flow frequency analysis is normally conducted to determine the maximum amount of water that could be extracted from the source basin (Gupta and van der Zaag 2008; Jain et al. 2005). Using this method, the water transfer capacity is calculated with a specified water supply reliability. However, as ecological recharge is often conducted during high flow periods, high flow frequency analysis should be conducted to understand the frequency and the water quantity that can be used for ecological recharge. Furthermore, the costs and benefits of ecological recharge need to be fully considered. In the case of the central route of SNWT, the water transfer has no operational costs as the pipeline fully relies on gravity. In other cases, the extra water for ecological recharge might incur pumping costs (Ming et al. 2017). Additional capital costs might also be incurred if the water transfer capacity needs to be increased to accommodate the increased flow for ecological recharge. In the meantime, the ecological benefits in the receiving region and flood alleviation benefits in the source region should be quantified where it is possible. A comprehensive evaluation of the benefits and impacts of the projects is crucial in the planning stage, especially considering the unintended eco-effects. Ecological recharge could be considered as a means to achieve a net positive impact for inter-basin water transfer projects.

Establishing optimal ecological recharge operations

Operational policies for regional ecological recharge, including when, where and how much to recharge, should be established for practical implementation. The challenge lies in the development of a recharge strategy for sustainable water management that is optimal in both the receiving and source regions.

First, the primary task in the development of recharge operations is to determine the amount of water that can be used, i.e., the surplus water in addition to the water demand in the recipient region. However, the stochastic nature of runoff in the source region and water demands in the recipient results in uncertainty in the amount of recharged water and the time taken for replenishment. Meanwhile, since ecological recharge is carried out on the premise of satisfying normal water demands, it is impossible to recharge a large amount of ecological water to the water-deficient area in a very short time, and thus the timing of ecological recharge is critical. Therefore, optimal recharge strategies should be developed such that the reliability of original water users in the receiving region is not compromised.

Second, the target areas for ecological water recharge, i.e., where to recharge, should be selected to maximize the social, economic, and ecological benefits. For example, the central route of SNWT project covers a recipient region with an area of 150,000km^2. There are numerous water bodies or systems of various types to be recharged, including irrigation districts, lakes, rivers, and wetlands. New technologies such as remote sensing and artificial intelligence should be incorporated in optimal strategy development. For example, remote sensing data and real-time flow data are used to assess the water shortage severity in different areas (Liu et al. 2018), long short-term memory networks are used to predict river flows, and deep reinforcement learning is used for developing operational strategies (Kratzert et al. 2018; Ni et al. 2019; Zhang et al. 2018).

The last issue is the allocation of water to the target recharged areas, i.e., how much to recharge. A large-scale optimal water resources allocation model can be established based on the water demands for recharged targets, which are determined considering ecological integrity, connectivity of water bodies, purification capacity, habitat communities, landscape and environment functions, etc. (Acreman and Dunbar 2004). Moreover, different recharge targets involve multiple stakeholders with potential conflicting interests. Therefore, coordinate theory should be adopted to allocate water based on the principle of fairness and to maximize the benefits (Sadegh et al. 2010).

Establishing a monitoring system for negative impacts

Although the inter basin water transfer brings some unintended ecological benefits through ecological recharges, it can also bring negative impacts, which should be carefully monitored, assessed and mitigated.

Ecological recharges may aggravate water conflicts and environmental degradation in the lower reach of the source region, for example by contributing to acidification, estuary salinization and damage to the ecological environment (Webber et al. 2015; Wilson et al. 2017; Yang and Cai 2011; Zhuang 2016). The philosophy of ecological recharge is to make use of flood water resources and have little impact on the source region, particularly during low flow periods. However, flooding is a natural hydrological process and can carry a large amount of sediment and nutrients downstream, and thus reduced flood discharges may affect biological productivity, biodiversity and ecological integrity in the downstream regions (Gibbins et al. 2001; Suen 2011; Suen and Eheart 2006; Zmijewski and Worman 2017). In the Gunnison River in western Colorado, for example, a flushing flow is needed to remove fines and sand from the riffles for the Colorado squawfish spawning (Milhous 1998). Moreover, the cumulative effect of hydrological alterations might cause the ecosystem to reach a tipping point (Dubé 2003; Scheffer et al. 2009). This should be carefully considered at the planning stage. For example, in order to mitigate the negative impacts of the central route of SNWT project on the Han River, a project transferring water from Yangtze River to Han River with a maximum capacity of $500m^3/s$ was conducted (Zhu et al. 2008).

For the water receiving region, when a large amount of externally imported water is discharged into the existing water bodies in a short period, (thus subjecting them to unnatural large and short-term variations), it can generate complex hydrological, chemical, biological and geomorphological impacts on the water systems and ecosystems (Davies et al. 1992). This includes limiting the availability of habitats and affecting the richness and abundance of invertebrate species (Suen and Eheart 2006). For example, the increased water depth and area at the Hong Lake due to the eastern route of SNWT project reduced the abundance and distribution of submerged macrophytes and affected the fish communities and assemblages (Lin et al. 2017). Ecological recharges also result in movement of physicochemical regimes, such as micro-plastic pollution (Blettler et al. 2018), heavy metals (Li et al. 2008; Li and Zhang 2010), and nutrients (Zeng et al. 2015) from the donor to the recipients. This might deteriorate the water quality and increase eutrophication risk, and further disrupt the ecosystem balance, impair the function and structure of the local ecosystems and thus reduce their stability and resilience in the recharged region (Zeng et al. 2015; Zhai et al. 2010). For example, micro-plastic pollution, one of the top ten emerging issues reported by the United Nations Environment Program (UNEP) in recent Year Books, impacts freshwater fish, birds, and zooplankton organisms (Biginagwa et al. 2016; Blettler et al. 2018). The heavy metals, one of the most serious pollutants, transported through the water transfer project to the receiving region will lead to the integration and accumulation of heavy metal in surface water, groundwater, soil, terrestrial and aquatic plants and animals, and further lead to hazards on human (Li et al. 2008; Li and Zhang 2010; Rattan et al. 2005). Most importantly, water transfer might lead to the introduction of non-native and often invasive aquatic and terrestrial plants and animals; this is an unintended ecological consequence in the receiving region and is one of the serious concerns regarding water transfer (Chamier et al. 2012; Dextrase and Mandrak 2006; Gurevitch and Padilla 2004). Non-native and invasive species affect the balance of ecosystems from water quantity and quality aspects, and can lead to the extinction of local species (Chamier et al. 2012).

As demonstrated above, ecological recharge might result in negative impacts, which should be comprehensively evaluated. Monitoring systems are needed to collect data and establish an early warning system for long term negative impact to human health and ecosystems. Moreover, potential negative impacts should be considered at the planning stages and countermeasures should be taken to reduce them. For example, 22 wastewater treatment plants and the Yangtze–Han Water Transfer Project diverting water from the upstream were constructed to mitigate the negative effect of the central route of SNWT project on the downstream Han River and receiving region (Zhu et al. 2008).

Establishing a coordination framework

A coordination framework should be established for effective communication and coordination between different stakeholders to maximize the overall benefits of recharge. Inter-basin water transfer often involves varying ecological and environmental needs across different regions, and thus the framework can coordinate conflicting interests that might arise and develop best practices for recharge. Further, financial instruments can be considered to balance regional inequalities in ecological benefits received and used to encourage investments for new monitoring and information systems. It should be noted that the restoration of ecological systems is a long-term goal, and recharge should be integrated with other interventions in order to achieve sustainable management of water and ecological systems.

Data Availability Statement

The Landsat 8 Operational Land Imager (OLI) imagery is downloaded from the website: https://earthexplorer.usgs.gov/

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